

## METHOD AND APPARATUS FOR ERROR VECTOR MAGNITUDE REDUCTION

5

### Field of the Invention

The present invention relates generally to wireless communications, but more specifically to methods and systems for error vector magnitude reduction.

10

### Background of the Invention

Wireless communication systems are an integral component of the ongoing technology revolution. In fact, mobile radio communication systems, such as cellular telephone systems, are evolving at an exponential rate. In a cellular system, a coverage area is divided into a plurality of "cells." A cell is the coverage area of a base station or transmitter. Low power transmitters are utilized, so that frequencies used in one cell can also be used in cells that are sufficiently distant without interference. Hence, a cellular telephone user, whether mired in traffic gridlock or attending a meeting, can transmit and receive phone calls so long as the user is within a "cell" served by a base station.

20

One implementation of a cellular network 100 is depicted in block form in **FIG. 1**. The network 100 is divided into four interconnected components or subsystems: a Mobile Station (MS) 106, a Base Station Subsystem (BSS) 102, a Network Switching Subsystem (NSS) 104, and an Operation Support Subsystem (OSS) 118. Generally, MS 106 is the mobile equipment or phone carried by the user. BSS 102 interfaces with multiple mobiles to manage the radio transmission paths between MSs 106 and NSS 104. In turn, NSSs104 manages system-switching functions and facilitates communications with other networks such as the PSTN and the ISDN. OSS 118 facilitates operation and maintenance of the network.

25

30

MSs 106 communicate with BSS 102 across a standardized radio air interface 108. BSS 102 is comprised of multiple base transceiver stations (BTS) 110 and base station controllers (BSC) 114. A BTS 110 is usually in the center of a cell and consists of one or more radio transceivers with an antenna. It establishes radio

links and handles radio communications over the air interface with MSs 106 within the cell. The transmitting power of the transceiver defines the size of the cell. Each  
5 BSC 102 manages multiple transceivers. The total number of transceivers per a particular controller could be in the hundreds. The transceiver-controller communication is over a standardized "Abis" interface 112. BSC 102 allocates and manages radio channels and controls handovers of calls between its transceivers.

10 BSC 102, in turn, communicates with NSS 104 over a standardized interface 116. For example, in a GSM system, which will be discussed infra, the interface uses an SS7 protocol and allows use of base stations and switching equipment made by different manufacturers. A Mobile Switching Center (MSC) 122 is the primary component of NSS 104. MSC 122 manages communications between mobile  
15 subscribers and between mobile subscribers and public networks 130. Examples of public networks 130 that the mobile switching center may interface with include Integrated Services Digital Network (ISDN) 132, Public Switched Telephone Network (PSTN) 134, Public Land Mobile Network (PLMN) 136, and Packet Switched Public Data Network (PSPDN) 138.

20 MSC 122 typically will interface with several databases to manage communication and switching functions. For example, MSC 122 may interface with Home Location Register (HLR) 124 that contains details on each subscriber residing within the area served by the mobile switching center. There may also be a Visitor Location Register (VLR) 126 that temporarily stores data about roaming subscribers within a coverage area of a particular mobile switching center. An Equipment  
25 Identity Register (EIR) 120 that contains a list of mobile equipment may also be included. Further, equipment that has been reported as lost or stolen may be stored on a separate list of invalid equipment that allows identification of subscribers attempting to use such equipment. Finally, there may be an Authorization Center (AuC) 128 that stores authentication and encryption data and parameters that verify  
30 a subscriber's identity.

There are several technologies in use today for different implementations of cellular network 100. When wireless telecommunications began in North America

back in the 1950s, an analogue standard called Advanced Mobile Phone Service (AMPS) was used. AMPS operated in the frequency spectrum from 824 to 894 MHz. This spectrum was then divided into 30 KHz channels for use by MSs 106 within cellular network 100. In order to allow full duplex operation, a 30Khz channel is reserved for each MS 106 to transmit on, and a 30 KHz channel is reserved for each MS 106 to receive on. These two channels are separated within the frequency spectrum by 45 MHz. Thus, a MS 106 transmitting on a channel at 831.21 MHz would receive at 876.21 MHz.

Dividing the frequency spectrum into multiple equally spaced channels is called Frequency Division Multiple Access (FDMA) and is illustrated in **FIG. 2A**. As can be seen, there are a limited number of channels 202 that can be used within the fixed frequency spectrum from 824 to 894 MHz. As a result, new technologies were developed in order to increase the capacity (number of channels) that could be supported by a cellular network 100. The first of these technologies was called Narrowband Advanced Mobile Phone Service (NAMPS). The key difference between NAMPS and AMPS is the use of a 10Khz channel in the former. Thus, the capacity of a NAMPS system is three times the capacity of an AMPS system.

Eventually, digital technologies evolved to address the capacity issue and to improve the quality and functionality of the services provided by cellular network 100. The major difference between digital and analogue is the method used to transmit data between MS 106 and BSS 102. In an analogue scheme, the information is encoded as proportional variations in a frequency modulation (FM). In a digital scheme, the information is first digitized and then encoded using various complex modulation schemes. The modulated signal is then transmitted to BSS 102. Additionally, as a result of the digital schemes and the enhanced features they enable, the frequency spectrum from 1.85 GHz to 1.99 GHz has been allocated for new cellular type services called Personal Communications Service (PCS).

The primary digital technologies used in North American are Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). There are several TDMA technologies currently available in the United States. One is the

North American-TDMA system (NA-TDMA), also known as Digital-AMPS (D-AMPS). TDMA employs time slots to put multiple calls on the same channel. As illustrated in **FIG. 2B**, NA-TDMA uses the same channel scheme as AMPS; however, each channel is divided into six time slots 204a-204f. Each slot is then assigned to a different user. Thus, the capacity of a NA-TDMA system is six times the capacity of an AMPS system and twice the capacity of a NAMPS system. Before 1995, NA-TDMA was governed by the IS-54 standard. IS-54 is being replaced, however, by IS-136, which incorporates implementation in the PCS band, a new Digital Control Channel (DCCH), and new user services.

Another TDMA system that developed in Europe, where a similar transition from analog to digital technologies took place, is the GSM system. GSM has been adopted for use in the United States as PCS1900, which is now offered in the PCS band.

CDMA, on the other hand, is a completely different type of multiple access scheme. In CDMA, channels are not allocated by dividing the spectrum in frequency or time. Instead, a 1.25 MHz channel is used for all users within a cell. The transmission signal is prepared by first digitizing the data and then multiplying the digitized data by a wide-bandwidth pseudo noise code (pn)-sequence. Thus, as illustrated in **FIG. 2C**, each transmission 206a, 206b, 206c, and 206d appears as noise to all other transmissions. In order to recover the signal at a receiver, each user is given a specific (pn)-sequence that is recognized by that user's MS 106 and BSS 102. Therefore, only transmissions coded using the specific (pn)-sequence are recognized and the rest of the transmissions are regarded as noise.

Both TDMA and CDMA employ a technique known as modulation, which mixes the digital signal bit stream onto a Radio Frequency (RF) carrier of a predetermined frequency prior to the amplification stage of a transmitter. In its modulated form, the signal becomes subject to a host of obstacles as it travels over the airwaves. Dropouts, signal wells, and crossover interference from neighboring channels are familiar mobile communication vulnerabilities that cause annoying disturbance in analog communication, but in the digital realm they make

5 reconstruction of the original signal difficult or impossible. Such difficulties often manifest themselves digitally as misread bits during demodulation by the RF receiver. Conversations or messages transmitted digitally are frequently made undecipherable by a receiver's inability to faithfully reconstruct the bit stream. Thus, it is critical that the modulated signal be as accurate as possible in order to preserve the integrity of the encoded bitstream.

10 In this regard, one important design parameter of modern wireless systems is a quantity known as the Error Vector Magnitude (EVM). EVM data is gathered near the final stage in a typical RF transmitter, just after signal amplification. EVM is a measure of the amount of overshoot detected at the transmitter output and is usually plotted in the IQ plane. EVM is a root cause of overshoot, which results in errors in the interpretation of phase state transitions. These errors alter the transmitted bit stream when the receiver tries to reconstruct the original signal. EVM can therefore be used as a metric for identifying deviations from ideal state transitions and must be kept to a practical minimum.

### Summary of the Invention

20 The present invention comprises a predetermined error vector magnitude reduction circuit that includes the use of a lookup table containing bit patterns, which were predetermined to cause overshoot. These predetermined bit patterns are used to supply modified output data that does not cause overshoot. In one embodiment, modified analog data pre-stored in the lookup table replaces the output of digital-to-analog converters within the circuit. In another embodiment, modified digital bit patterns replace the inputs to the digital-to-analog converters. In either embodiment, the resulting modified output is then fed into a mixing stage or stages of a transmitter. The invention also comprises wireless communication handset that includes a transmitter containing a predetermined error vector magnitude reduction circuit.

25 30 A method for pre-loading the lookup table with pre-determined characteristic bit patterns derived from offshoot scatter patterns detected during testing of the

circuit is also provided. The method may also comprise the steps required to  
compare the characteristic bit patterns with the input signals and substitute the  
corresponding modified data for the input signals when a match is made in the  
lookup table.

Further embodiments and implementations of the invention are also  
disclosed and are explained in detail below.

### **Brief Description of the Drawings**

In the figures of the accompanying drawings, like reference numbers  
correspond to like elements, in which:

**FIG. 1** is a diagram illustrating a typical cellular communications system.

**FIG. 2A** is a diagram illustrating the channel structure in a FDMA system.

**FIG. 2B** is a diagram illustrating the channel structure in a TDMA system.

**FIG. 2C** is a diagram illustrating the channel structure in a CDMA system.

**FIG. 3A** is a block diagram illustrating a first embodiment of a wireless  
transmitter.

**FIG. 3A** is a block diagram illustrating a second embodiment of a wireless  
transmitter.

**FIG. 4** is a diagram illustrating quadrature modulation using quadrature  
phase shift keying.

**FIG. 5** is a constellation diagram illustrating typical phase state transition in  
quadrature phase shift keying system.

**FIG. 6** is a close-up of a portion of the constellation diagram of **FIG. 5**  
illustrating error vector magnitude.

**FIG. 7** is a block diagram illustrating a transmitter system with a feedback  
block.

**FIG. 8** is a block diagram illustrating a first embodiment of a predetermined  
error vector magnitude reduction circuit in accordance with the invention.

**FIG. 9** is a block diagram illustrating a second embodiment of a predetermined error vector magnitude reduction circuit in accordance with the invention.

**FIG. 10** is a block diagram of a wireless transmitter comprising an error vector magnitude circuit such as the one illustrated in **FIG. 8** or **FIG 9**.

**FIG. 11** is a process flow diagram illustrating a method of predetermined error vector magnitude reduction in accordance with the invention.

**FIG 12** is a process flow diagram illustrating a method of using a lookup table to prevent or reduce error vector magnitude in accordance with the invention.

### **Detailed Description**

**FIG. 3A** illustrates a sample embodiment of a transmitter 300 belonging to a mobile station in a wireless communications system. Transmitter 300 comprises a baseband processor 302, which generates digital inphase (I) and quadrature (Q) data signals. These data signals represent information that has undergone coding in the digital domain. Transmitter 300 also includes an inphase Digital-to-Analog Converter (DAC) 304 and a quadrature DAC 306. DACs 304 and 306 transform the inphase and quadrature digital signals into inphase and quadrature analog signals, respectively. In particular, the inphase and quadrature digital undergo Quadrature Phase Shift Keying (QPSK), which is a popular modulation format used in digital wireless phones. QPSK uses the simultaneous transmission of two Phase Shift Keying (PSK) signals where one is in quadrature (shifted in phase by 90°) to the other. Adder 308, which is part of mixing block 314, adds the inphase and quadrature analog signals, producing a single-ended analog signal. Mixing block 314 transforms the single-ended analog signal into an RF signal.

In a direct conversion transmitter, mixing block 314 comprises one mixer 310, which modulates the single-ended analog signal onto an RF carrier signal to produce the RF signal. In a more typical embodiment, transmitter 300 is an Intermediate Frequency (IF) transmitter, which comprises two mixers 310 and 312 within mixing block 314. In this case, mixer 310 mixes the single-ended analog

5 signal up to an IF signal, and mixer 312 mixes the IF signal up to the RF signal. The RF signal is sent to Power Amplifier (PA) 316, which amplifies the RF signal to a sufficient power level for transmission by antenna 318.

10 An alternative embodiment of a transmitter 320 is illustrated in **FIG. 3B**. Transmitter 320 is differentiated from transmitter 300 by an alternative configuration of mixing block 314. In this embodiment, the inphase and quadrature signals are mixed up to inphase and quadrature RF signals independently of each other. In a direct conversion transmitter the mixing is done using one inphase RF mixer 322 and one quadrature RF mixer 324. But in an IF transmitter, mixers 322 and 324 are inphase and quadrature IF mixers, which generate inphase and quadrature IF signals. RF mixers 326 and 328 mix the inphase and quadrature IF signals up to inphase and quadrature RF signals. Regardless of whether transmitter 320 is a direct conversion or IF transmitter, the inphase and quadrature RF signals are combined in adder 330 and sent to PA 316 for amplification before transmission by antenna 318.

15 As mentioned previously, EVM, which is measured at the output of PA 318, is a key design parameter. EVM is due to non-linearity in the transmitter components that are between baseband processor 302 and antenna 318, and mismatches in amplitude and/or phase difference between the inphase and quadrature signal paths. These problems cause the vector magnitude and phase representations of the inphase and quadrature data to be incorrect. The resulting error in the magnitude and/or phase can cause overshoot in the transitions from state to state at the transmitter's output.

20 Understanding how phase state transitions can be used to encode digital signals requires a basic knowledge of modulation. QPSK modulation, for example, is a phase shift key scheme used in TDMA systems to encode the bit patterns of a digital signal onto an analog waveform by manipulating the waveform's phase. As illustrated in **FIG. 4**, QPSK encodes the inphase and quadrature bits into four different symbol states that are represented by a two bit symbol and associated phase. The phase for each state is 90° out of phase with adjacent states. These



states can be represented on the constellation diagram of **FIG. 5** by points 502, 504, 506, and 508. Ideally, the magnitude of these points is unity. Problems with the linearity of the transmitter will, however, cause errors in the magnitude or phase. Errors in the phase will cause the actual vector position to slew toward the adjacent states as if it was moving along the perimeter of a unit circle. Errors in the magnitude, on the other hand, will cause the vector position to slew in and out along an axis extending from the origin.

Also illustrated in **FIG. 5** are the transitions from state to state. Due to the errors in magnitude and phase, the actual vector position resulting from each transition will not align with the ideal vector position for each state. This misalignment is illustrated more closely in **FIG. 6**. Thus, the ideal position vector 612 and the actual position vector 614 will not coincide, creating error vector 616. The result of a succession of state transitions will, therefore, be a scatter pattern 510 (**FIG. 5**) of actual positions and their associated error vectors 616. Certain specific scatter patterns 510 will cause overshoot in the transition from one state to the next and will result in high error rates in the transmitted data.

Existing approaches to EVM minimization have traditionally focused on careful component selection and tolerance adjustments at each stage in the transmitter circuit, as well as attempts at linearization of the amplification stage. Popular linearization techniques include negative feedback, predistortion, and feedforward techniques.

**FIG. 7** illustrates a general block diagram of a negative feedback network 700. Feedback block 720 subtracts a portion of the output from PA 716 from a signal at some earlier stage in the system in order to improve system linearity. Negative feedback loops, like the well-known Cartesian Feedback approach, are often deployed in transmitters to improve the linearity of PA 716. This approach, however, has limitations. First, the linearization achieved is dependent upon a close match in both gain and phase between mixing block 714 and feedback block 720. Second, tight control over the components must be guaranteed to ensure the stability

of the loop. Finally, feedback techniques undesirably reduce the forward gain of the amplifier stage.

5 Predistortion is aimed at improving the linearity of PA 716, as well. In predistortion, linearization is achieved by applying distortions to the digital inphase and quadrature data. Distortion coefficients are generated based on known characteristics of PA 716. The coefficients are used for distorting the signal prior to entering the digital-to-analog conversion stage. Adaptive predistortion goes one step  
10 further, adding a feedback loop that updates the coefficients by periodically sensing the output of PA 716. Adding the feedback loop, however, subjects the adaptive predistortion method to the same ill side-effects of Cartesian feedback. Additionally, each of the above approaches constantly acts on the digital inphase and quadrature signals in order to improve linearization. Thus, these approaches act at a  
15 constant cost to system performance and are not guaranteed to eliminate overshoot. Further, by modifying the digital data, these approaches are introducing incorrect data into the transmitted information.

Feedforward linearization does not use feedback. Instead, an attenuated sample of the output from nonlinear PA 716 is subtracted from a time-delayed  
20 version of the input of PA 716, leaving behind only the unwanted frequency components of the output of PA 716. This resulting error signal is then fed into a second amplifier, whose output is subtracted from a time-delayed sample of the output of PA 716, generating a clean signal. A major drawback of the feedforward technique is the required careful matching between the two signal paths. That is, the  
25 time delay introduced by the first delay element must closely match the natural time delay introduced by the nonlinear PA in order for the signal subtraction stage to generate a pure error signal. As with the previous approaches, there is no guarantee that overshoot can be avoided. Moreover, each of the above approaches has  
30 significant disadvantages in terms of component costs, component area, manufacturing yield, and transmitter performance.

**FIG. 8** illustrates a transmitter 800 in accordance with one embodiment of the claimed invention. Transmitter 800 comprises baseband processor 802, which

produces digital inphase and quadrature signals and stores these signals in inphase and quadrature registers 804 and 806, respectively. The outputs of registers 804 and 806 are coupled to inphase and quadrature DACs 808 and 810 respectively, the outputs of which are inphase and quadrature analog signals respectively. The analog signals are mixed up to an RF signal in mixing block 816, which can use either direct conversion or IF mixing. The RF signal is amplified by PA 818 and transmitted via antenna 820.

While it is important to ensure that transmitter 800 is designed for maximum linearity, this is not a guarantee that overshoot will not occur. Thus, transmitter 800 includes lookup table 812. Lookup table 812 takes advantage of the fact that overshoot can be correlated to specific overshoot patterns 510 (**FIG. 5**). Through testing for these patterns 510, correlations to specific digital inphase and quadrature bit patterns can be developed. These specific bit patterns are stored in lookup table 812 as predetermined digital inphase and quadrature bit patterns. In addition, for each of the predetermined inphase and quadrature bit patterns, modified digital inphase and quadrature bit patterns that do not cause overshoot, are stored in lookup table 812.

Therefore, the predetermined and modified bit patterns can be prerecorded in lookup table 812. Lookup table 812 is typically stored in a storage device such as in SRAM, Flash, EPROM, EEPROM, or DRAM. Then, as digital inphase and quadrature data is generated by baseband processor 802, it is stored in registers 804 and 806. The bit patterns stored in registers 804 and 806 are compared with the predetermined bit patterns in table 812. If there is a match, then the modified bit patterns are read out of table 812 and replace the registered bit patterns as the inputs to DACs 808 and 810. In this way, overshoot is avoided.

Alternative embodiments implement lookup table 812 in firmware or in software. Maintaining table 812 in software has the added advantage that table 812 can easily be updated if later testing or performance requires.

Modifying the digital inphase and quadrature data will, of course, result in the inclusion of erroneous data in the transmitted signal. This can be overcome,

however, by the embodiment illustrated in **FIG. 9**. Transmitter 900, of **FIG. 9**, includes a slightly different lookup table 902. In lookup table 902, modified analog inphase and quadrature data is stored as opposed to modified digital bit patterns. When there is a match between the registered bit patterns and the predetermined bit patterns, the modified analog data replaces the data at the output of DACs 808 and 810. By modifying the analog data, overshoot can be avoided without affecting the accuracy of the data transmitted and ultimately received at a transmission destination.

The advantage of modifying the analog data is illustrated by looking at the digital-to-analog conversion process. The conversion process takes a digital string of high and low voltages and transforms them into a sinusoidal analog waveform that accurately represents the data encoded on the digital string. The analog waveform is quantized into a plurality of levels in order to improve accuracy. The digital data is then grouped into input frames of a length sufficient to represent a particular level. For example, in one embodiment, the analog signal has 16 levels. Therefore, the digital inputs are grouped 4-bits at a time, because  $2^4=16$ . Thus, each 4-bit input to DACs 804 and 806 represent a level in the analog output of each DAC. When there is a match, however, between the registered data and the predetermined data, then the modified analog data is read out of lookup table 902. The modified analog data can alter the level of the analog signal for that conversion, without corrupting the information content. This is because the changing of one level will have negligible impact on the overall analog waveform. For the embodiment discussed above, the registered data and predetermined data would obviously be 4-bits wide.

Further enhancement is obtained, in one particular embodiment, due to the fact that the digital data is eight times oversampled. Therefore, each single digital information bit is actually represented by eight bits at the output of baseband processor 802. Thus, the modification is done with a  $1/8^{\text{th}}$  bit resolution, lessening the impact on the analog waveform even further.

**FIG. 10** illustrates a transmitter 1000 that incorporates a predetermined error vector magnitude reduction circuit 814, which is coupled to the output of a baseband processor 1002. The output of circuit 814 is coupled to mixing block 1006, the output of which drives PA 1008 and, subsequently, antenna 1010. The example embodiments above have generally discussed the invention with respect to a mobile station in a wireless communications network. Those skilled in the art will realize, however, that transmitter 1000 can be implemented within a variety of systems. For example, those skilled in the art will realize that any system dependent on preventing overshoot and minimizing EVM will be able to incorporate transmitter 1000. In particular, handsets within a cordless phone system, a wireless local loop, or a satellite communications system are able to utilize transmitter 1000. As such, the embodiments above, as they relate to mobile stations in a wireless communications system, are by way of example only, and are not intended to limit the scope of the invention in any way.

In addition to the above apparatus, there is also provided a method for predetermined error vector magnitude reduction, which is illustrated by the steps in **FIG. 11**. First in step 1102, testing is done to detect overshoot in a transmitter, such as transmitter 800 or 900 described above. Then, in step 1104, the incidents of overshoot are correlated to specific scatter patterns. These scatter patterns are then correlated to specific digital bit patterns in step 1106. For example, the scatter patterns are correlated to specific inphase and quadrature digital bit patterns generated by a baseband processor 802. Next, in step 1108, a lookup table is formed that comprises the digital bit patterns identified in step 1106, which are referred to as predetermined digital bit patterns, and modified data. The modified data is designed to eliminate the overshoot. Finally, in step 1110, the lookup table is used to eliminate the overshoot during operation of the transmitter.

**FIG. 12** illustrates one embodiment of a process of using the lookup table to eliminate overshoot. In step 1202, digital data is generated. For example, this data may be digital inphase and quadrature data generated by a baseband processor 802. Then in step 1204, the digital data is stored in registers, such as registers 804 and

806. The data in the registers is then compared, in step 1206, to the predetermined  
bit patterns stored in the lookup table. If there is a match, then in step 1208 the  
modified data in the lookup table is used. If there is no match, then in step 1210 the  
original digital data is used. Moreover, in one embodiment, the modified data in the  
lookup table represents modified digital data. In another embodiment, however, the  
modified data represents modified analog data.

5

10

15

20

25

30

11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65  
66  
67  
68  
69  
70  
71  
72  
73  
74  
75  
76  
77  
78  
79  
80  
81  
82  
83  
84  
85  
86  
87  
88  
89  
90  
91  
92  
93  
94  
95  
96  
97  
98  
99  
100  
101  
102  
103  
104  
105  
106  
107  
108  
109  
110  
111  
112  
113  
114  
115  
116  
117  
118  
119  
120  
121  
122  
123  
124  
125  
126  
127  
128  
129  
130  
131  
132  
133  
134  
135  
136  
137  
138  
139  
140  
141  
142  
143  
144  
145  
146  
147  
148  
149  
150  
151  
152  
153  
154  
155  
156  
157  
158  
159  
160  
161  
162  
163  
164  
165  
166  
167  
168  
169  
170  
171  
172  
173  
174  
175  
176  
177  
178  
179  
180  
181  
182  
183  
184  
185  
186  
187  
188  
189  
190  
191  
192  
193  
194  
195  
196  
197  
198  
199  
200  
201  
202  
203  
204  
205  
206  
207  
208  
209  
210  
211  
212  
213  
214  
215  
216  
217  
218  
219  
220  
221  
222  
223  
224  
225  
226  
227  
228  
229  
230  
231  
232  
233  
234  
235  
236  
237  
238  
239  
240  
241  
242  
243  
244  
245  
246  
247  
248  
249  
250  
251  
252  
253  
254  
255  
256  
257  
258  
259  
260  
261  
262  
263  
264  
265  
266  
267  
268  
269  
270  
271  
272  
273  
274  
275  
276  
277  
278  
279  
280  
281  
282  
283  
284  
285  
286  
287  
288  
289  
290  
291  
292  
293  
294  
295  
296  
297  
298  
299  
300  
301  
302  
303  
304  
305  
306  
307  
308  
309  
310  
311  
312  
313  
314  
315  
316  
317  
318  
319  
320  
321  
322  
323  
324  
325  
326  
327  
328  
329  
330  
331  
332  
333  
334  
335  
336  
337  
338  
339  
340  
341  
342  
343  
344  
345  
346  
347  
348  
349  
350  
351  
352  
353  
354  
355  
356  
357  
358  
359  
360  
361  
362  
363  
364  
365  
366  
367  
368  
369  
370  
371  
372  
373  
374  
375  
376  
377  
378  
379  
380  
381  
382  
383  
384  
385  
386  
387  
388  
389  
390  
391  
392  
393  
394  
395  
396  
397  
398  
399  
400  
401  
402  
403  
404  
405  
406  
407  
408  
409  
410  
411  
412  
413  
414  
415  
416  
417  
418  
419  
420  
421  
422  
423  
424  
425  
426  
427  
428  
429  
430  
431  
432  
433  
434  
435  
436  
437  
438  
439  
440  
441  
442  
443  
444  
445  
446  
447  
448  
449  
450  
451  
452  
453  
454  
455  
456  
457  
458  
459  
460  
461  
462  
463  
464  
465  
466  
467  
468  
469  
470  
471  
472  
473  
474  
475  
476  
477  
478  
479  
480  
481  
482  
483  
484  
485  
486  
487  
488  
489  
490  
491  
492  
493  
494  
495  
496  
497  
498  
499  
500  
501  
502  
503  
504  
505  
506  
507  
508  
509  
510  
511  
512  
513  
514  
515  
516  
517  
518  
519  
520  
521  
522  
523  
524  
525  
526  
527  
528  
529  
530  
531  
532  
533  
534  
535  
536  
537  
538  
539  
540  
541  
542  
543  
544  
545  
546  
547  
548  
549  
550  
551  
552  
553  
554  
555  
556  
557  
558  
559  
560  
561  
562  
563  
564  
565  
566  
567  
568  
569  
570  
571  
572  
573  
574  
575  
576  
577  
578  
579  
580  
581  
582  
583  
584  
585  
586  
587  
588  
589  
590  
591  
592  
593  
594  
595  
596  
597  
598  
599  
600  
601  
602  
603  
604  
605  
606  
607  
608  
609  
610  
611  
612  
613  
614  
615  
616  
617  
618  
619  
620  
621  
622  
623  
624  
625  
626  
627  
628  
629  
630  
631  
632  
633  
634  
635  
636  
637  
638  
639  
640  
641  
642  
643  
644  
645  
646  
647  
648  
649  
650  
651  
652  
653  
654  
655  
656  
657  
658  
659  
660  
661  
662  
663  
664  
665  
666  
667  
668  
669  
670  
671  
672  
673  
674  
675  
676  
677  
678  
679  
680  
681  
682  
683  
684  
685  
686  
687  
688  
689  
690  
691  
692  
693  
694  
695  
696  
697  
698  
699  
700  
701  
702  
703  
704  
705  
706  
707  
708  
709  
710  
711  
712  
713  
714  
715  
716  
717  
718  
719  
720  
721  
722  
723  
724  
725  
726  
727  
728  
729  
730  
731  
732  
733  
734  
735  
736  
737  
738  
739  
740  
741  
742  
743  
744  
745  
746  
747  
748  
749  
750  
751  
752  
753  
754  
755  
756  
757  
758  
759  
760  
761  
762  
763  
764  
765  
766  
767  
768  
769  
770  
771  
772  
773  
774  
775  
776  
777  
778  
779  
780  
781  
782  
783  
784  
785  
786  
787  
788  
789  
790  
791  
792  
793  
794  
795  
796  
797  
798  
799  
800  
801  
802  
803  
804  
805  
806  
807  
808  
809  
810  
811  
812  
813  
814  
815  
816  
817  
818  
819  
820  
821  
822  
823  
824  
825  
826  
827  
828  
829  
830  
831  
832  
833  
834  
835  
836  
837  
838  
839  
840  
841  
842  
843  
844  
845  
846  
847  
848  
849  
850  
851  
852  
853  
854  
855  
856  
857  
858  
859  
860  
861  
862  
863  
864  
865  
866  
867  
868  
869  
870  
871  
872  
873  
874  
875  
876  
877  
878  
879  
880  
881  
882  
883  
884  
885  
886  
887  
888  
889  
890  
891  
892  
893  
894  
895  
896  
897  
898  
899  
900  
901  
902  
903  
904  
905  
906  
907  
908  
909  
910  
911  
912  
913  
914  
915  
916  
917  
918  
919  
920  
921  
922  
923  
924  
925  
926  
927  
928  
929  
930  
931  
932  
933  
934  
935  
936  
937  
938  
939  
940  
941  
942  
943  
944  
945  
946  
947  
948  
949  
950  
951  
952  
953  
954  
955  
956  
957  
958  
959  
960  
961  
962  
963  
964  
965  
966  
967  
968  
969  
970  
971  
972  
973  
974  
975  
976  
977  
978  
979  
980  
981  
982  
983  
984  
985  
986  
987  
988  
989  
990  
991  
992  
993  
994  
995  
996  
997  
998  
999  
1000  
1001  
1002  
1003  
1004  
1005  
1006  
1007  
1008  
1009  
1010  
1011  
1012  
1013  
1014  
1015  
1016  
1017  
1018  
1019  
1020  
1021  
1022  
1023  
1024  
1025  
1026  
1027  
1028  
1029  
1030  
1031  
1032  
1033  
1034  
1035  
1036  
1037  
1038  
1039  
1040  
1041  
1042  
1043  
1044  
1045  
1046  
1047  
1048  
1049  
1050  
1051  
1052  
1053  
1054  
1055  
1056  
1057  
1058  
1059  
1060  
1061  
1062  
1063  
1064  
1065  
1066  
1067  
1068  
1069  
1070  
1071  
1072  
1073  
1074  
1075  
1076  
1077  
1078  
1079  
1080  
1081  
1082  
1083  
1084  
1085  
1086  
1087  
1088  
1089  
1090  
1091  
1092  
1093  
1094  
1095  
1096  
1097  
1098  
1099  
1100  
1101  
1102  
1103  
1104  
1105  
1106  
1107  
1108  
1109  
1110  
1111  
1112  
1113  
1114  
1115  
1116  
1117  
1118  
1119  
1120  
1121  
1122  
1123  
1124  
1125  
1126  
1127  
1128  
1129  
1130  
1131  
1132  
1133  
1134  
1135  
1136  
1137  
1138  
1139  
1140  
1141  
1142  
1143  
1144  
1145  
1146  
1147  
1148  
1149  
1150  
1151  
1152  
1153  
1154  
1155  
1156  
1157  
1158  
1159  
1160  
1161  
1162  
1163  
1164  
1165  
1166  
1167  
1168  
1169  
1170  
1171  
1172  
1173  
1174  
1175  
1176  
1177  
1178  
1179  
1180  
1181  
1182  
1183  
1184  
1185  
1186  
1187  
1188  
1189  
1190  
1191  
1192  
1193  
1194  
1195  
1196  
1197  
1198  
1199  
1200  
1201  
1202  
1203  
1204  
1205  
1206  
1207  
1208  
1209  
1210  
1211  
1212  
1213  
1214  
1215  
1216  
1217  
1218  
1219  
1220  
1221  
1222  
1223  
1224  
1225  
1226  
1227  
1228  
1229  
1230  
1231  
1232  
1233  
1234  
1235  
1236  
1237  
1238  
1239  
1240  
1241  
1242  
1243  
1244  
1245  
1246  
1247  
1248  
1249  
1250  
1251  
1252  
1253  
1254  
1255  
1256  
1257  
1258  
1259  
1260  
1261  
1262  
1263  
1264  
1265  
1266  
1267  
1268  
1269  
1270  
1271  
1272  
1273  
1274  
1275  
1276  
1277  
1278  
1279  
1280  
1281  
1282  
1283  
1284  
1285  
1286  
1287  
1288  
1289  
1290  
1291  
1292  
1293  
1294  
1295  
1296  
1297  
1298  
1299  
1300  
1301  
1302  
1303  
1304  
1305  
1306  
1307  
1308  
1309  
1310  
1311  
1312  
1313  
1314  
1315  
1316  
1317  
1318  
1319  
1320  
1321  
1322  
1323  
1324  
1325  
1326  
1327  
1328  
1329  
1330  
1331  
1332  
1333  
1334  
1335  
1336  
1337  
1338  
1339  
1340  
1341  
1342  
1343  
1344  
1345  
1346  
1347  
1348  
1349  
1350  
1351  
1352  
1353  
1354  
1355  
1356  
1357  
1358  
1359  
1360  
1361  
1362  
1363  
1364  
1365  
1366  
1367  
1368  
1369  
1370  
1371  
1372  
1373  
1374  
1375  
1376  
1377  
1378  
1379  
1380  
1381  
1382  
1383  
1384  
1385  
1386  
1387  
1388  
1389  
1390  
1391  
1392  
1393  
1394  
1395  
1396  
1397  
1398  
1399  
1400  
1401  
1402  
1403  
1404  
1405  
1406  
1407  
1408  
1409  
1410  
1411  
1412  
1413  
1414  
1415  
1416  
1417  
1418  
1419  
1420  
1421  
1422  
1423  
1424  
1425  
1426  
1427  
1428  
1429  
1430  
1431  
1432  
1433  
1434  
1435  
1436  
1437  
1438  
1439  
1440  
1441  
1442  
1443  
1444  
1445  
1446  
1447  
1448  
1449  
1450  
1451  
1452  
1453  
1454  
1455  
1456  
1457  
1458  
1459  
1460  
1461  
1462  
1463  
1464  
1465  
1466  
1467  
1468  
1469  
1470  
1471  
1472  
1473  
1474  
1475  
1476  
1477  
1478  
1479  
1480  
1481  
1482  
1483  
1484  
1485  
1486  
1487  
1488  
1489  
1490  
1491  
1492  
1493  
1494  
1495  
1496  
1497  
1498  
1499  
1500  
1501  
1502  
1503  
1504  
1505  
1506  
1507  
1508  
1509  
1510  
1511  
1512  
1513  
1514  
1515  
1516  
1517  
1518  
1519  
1520  
1521  
1522  
1523  
1524  
1525  
1526  
1527  
1528  
1529  
1530  
1531  
1532  
1533  
1534  
1535  
1536  
1537  
1538  
1539  
1540  
1541  
1542  
1543  
1544  
1545  
1546  
1547  
1548  
1549  
1550  
1551  
1552  
1553  
1554  
1555  
1556  
1557  
1558  
1559  
1560  
1561  
1562  
1563  
1564  
1565  
1566  
1567  
1568  
1569  
1570  
1571  
1572  
1573  
1574  
1575  
1576  
1577  
1578  
1579  
1580  
1581  
1582  
1583  
1584  
1585  
1586  
1587  
1588  
1589  
1590  
1591  
1592  
1593  
1594  
1595  
1596  
1597  
1598  
1599  
1600  
1601  
1602  
1603  
1604  
1605  
1606  
1607  
1608  
1609  
1610  
1611  
1612  
1613  
1614  
1615  
1616  
1617  
1618  
1619  
1620  
1621  
1622  
1623  
1624  
1625  
1626  
1627  
1628  
1629  
1630  
1631  
1632  
1633  
1634  
1635  
1636  
1637  
1638  
1639  
1640  
1641  
1642  
1643  
1644  
1645  
1646  
1647  
1648  
1649  
1650  
1651  
1652  
1653  
1654  
1655  
1656  
1657  
1658  
1659  
1660  
1661  
1662  
1663  
1664  
1665  
1666  
1667  
1668  
1669  
1670  
1671  
1672  
1673  
1674  
1675  
1676  
1677  
1678  
1679  
1680  
1681  
1682  
1683  
1684  
1685  
1686  
1687  
1688  
1689  
1690  
1691  
1692  
1693  
1694  
1695  
1696  
1697  
1698  
1699  
1700  
1701  
1702  
1703  
1704  
1705  
1706  
1707  
1708  
1709  
1710  
1711  
1712  
1713  
1714  
1715  
1716  
1717  
1718  
1719  
1720  
1721  
1722  
1723  
1724  
1725  
1726  
1727  
1728  
1729  
1730  
1731  
1732  
1733  
1734  
1735  
1736  
1737  
1738  
1739  
1740  
1741  
1742  
1743  
1744  
1745  
1746  
1747  
1748  
1749  
1750  
1751  
1752  
1753  
1754  
1755  
1756  
1757  
1758  
1759  
1760  
1761  
1762  
1763  
1764  
1765  
1766  
1767  
1768  
1769  
1770  
1771  
1772  
1773  
1774  
1775  
1776  
1777  
1778  
1779  
1780  
1781  
1782  
1783  
1784  
1785  
1786  
1787  
1788  
1789  
1790  
1791  
1792  
1793  
1794  
1795  
1796  
1797  
1798  
1799  
1800  
1801  
1802  
1803  
1804  
1805  
1806  
1807  
1808  
1809  
1810  
1811  
1812  
1813  
1814  
1815  
1816  
1817  
1818  
1819  
1820  
1821  
1822  
1823  
1824  
1825  
1826  
1827  
1828  
1829  
1830  
1831  
1832  
1833  
1834  
1835  
1836  
1837  
1838  
1839  
1840  
1841  
1842  
1843  
1844  
1845  
1846  
1847  
1848  
1849  
1850  
1851  
1852  
1853  
1854  
1855  
1856  
1857  
1858  
1859  
1860  
1861  
1862  
1863  
1864  
1865  
1866  
1867  
1868  
1869  
1870  
1871  
1872  
1873  
1874  
1875  
1876  
1877  
1878  
1879  
1880  
1881  
1882  
1883  
1884  
1885  
1886  
1887  
1888  
1889  
1890  
1891  
1892  
1893  
1894  
1895  
1896  
1897  
1898  
1899  
1900  
1901  
1902  
1903  
1904  
1905  
1906  
1907  
1908  
1909  
1910  
1911  
1912  
1913  
1914  
1915  
1916  
1917  
1918  
1919  
1920  
1921  
1922  
1923  
1924  
1925  
1926  
1927  
1928  
1929  
1930  
1931  
1932  
1933  
1934  
1935  
1936  
1937  
1938  
1939  
1940  
1941  
1942  
1943  
1944  
1945  
1946  
1947  
1948  
1949  
1950  
1951  
1952  
1953  
1954  
1955  
1956  
1957  
1958  
1959  
1960  
1961  
1962  
1963  
1964  
1965  
1966  
1967  
1968  
1969  
1970  
1971  
1972  
1973  
1974  
1975  
1976  
1977  
1978  
1979  
1980  
1981  
1982  
1983  
1984  
1985  
1986  
1987  
1988  
1989  
1990  
1991  
1992  
1993  
1994  
1995  
1996  
1997  
1998  
1999  
2000  
2001  
2002  
2003  
2004  
2005  
2006  
2007  
2008  
2009  
2010  
2011  
2012  
2013  
2014  
2015  
2016  
2017  
2018  
2019  
2020  
2021  
2022  
2023  
2024  
2025  
2026  
2027  
2028  
2029  
2030  
2031  
2032  
2033  
2034  
2035  
2036  
2037  
2038  
2039  
2040  
2041  
2042  
2043  
2044  
2045  
2046  
2047  
2048  
2049  
2050  
2051  
2052  
2053  
2054  
2055  
2056  
2057  
2058  
2059  
2060  
2061  
2062  
2063  
2064  
2065  
2066  
2067  
2068  
2069  
2070  
2071  
2072  
2073  
2074  
2075  
2076  
2077  
2078  
2079  
2080  
2081  
2082  
2083  
2084  
2085  
2086  
2087  
2088  
2089  
2090  
2091  
2092  
2093  
2094  
2095  
2096  
2097  
2098  
2099  
2100  
2101  
2102  
2103  
2104  
2105  
2106  
2107  
2108  
2109  
2110  
2111  
2112  
2113  
2114  
2115  
2116  
2117  
2118  
2119  
2120  
2121  
2122  
2123  
2124  
2125  
2126  
2127  
2128  
2129  
2130  
2131  
2132  
2133  
2134  
2135  
2136  
2137  
2138  
2139  
2140  
2141  
2142  
2143  
2144  
2145  
2146  
2147  
2148  
2149  
2150  
2151  
2152  
2153  
2154  
2155  
2156  
2157  
2158  
2159  
2160  
2161  
2162  
2163  
2164  
2165  
2166  
2167  
2168  
2169  
2170  
2171  
2172  
2173  
2174  
2175  
2176  
217